2021

Experimental Investigation of the Heat Conductivity of Natural Refrigerant Oil Mixtures

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ABSTRACT

The Montreal Protocol and especially the European F-Gas-regulation proclaim the reduction of refrigerants with high global warming potential (GWP). Over the next decades, the phase-down of the production and the use of high GWP hydrofluorocarbons (HFCs) is declared. One viable alternative for HFCs are natural refrigerants and their blends.

The modification, optimization as well as the simulation of refrigerant cycles for new refrigerants requires knowledge of the thermophysical properties of the alternative refrigerants and their mixtures with the refrigeration oil. While pure refrigerants are well explored, there is a lack of information about the properties of their blends as well as of the refrigerant lubricant mixtures. Among other properties, this includes the heat conductivity of the pure lubricant as well as the heat-conductivity of refrigerant lubricant mixtures.

The experimental setup and the results of the heat conductivity measurements of different lubricants such as polyol ester oils (POE) and mineral oils (MO) as well as of refrigerant–lubricant- mixtures with natural refrigerants and their blends are presented. The test cell according to the hot-wire method with platinum wires was specially developed for the measurement of refrigerant–lubricant- mixtures at different compositions. The measurements are performed at temperatures of up to 80 °C and pressures of up to 40 bar.

Keywords:
Heat conductivity, fluid properties, hot-wire method, lubricant-refrigerant mixture

1 INTRODUCTION

With the Kigali amendment the Montreal protocol forces a face- down of high GWP refrigerants. Energy labelling additionally requires a high performance of each part in any cooling or heating application. Household appliances represent a major part of these applications that aside from that need to be robust, durable, simple and cost effective. Most household appliances run with a lubricated compressor but do not have any lubricant separator. Therefore, lubricant carryover can occur which depends on temperature and pressure. Furthermore, the solubility of refrigerant in lubricant depends also on pressure and temperature. For that reason, the knowledge of the thermodynamic properties of lubricant-refrigerant mixtures is very important. Especially in the household appliances, hydrocarbon refrigerants such as propane and iso-butane are already common, but the use of zeotropic mixtures could improve the performance of these applications. While pure refrigerants are mainly well investigated, there is a lack of information about the properties of their blends as well as of their refrigerant-lubricant mixtures. In this paper, the zeotropic mixtures methoxymethane (DME) and propane with a mineral oil ISO VG10 and a polyol ester oil ISO VG100 are selected as possible low GWP refrigerants and appropriate lubricants for use in these appliances. Both mixtures and their specific lubricants have no miscibility gap in the temperature range investigated, which was demonstrated by solubility measurements (Nosbers, et al., 2018) (Nosbers, et al., 2019). In this paper the heat conductivity of the mentioned mixtures was examined at different temperatures and different mass fractions (w%).

2 MEASUREMENT PRINCIPLES

Heat conductivity, which is normally measured with a hot-wire bridge, describes the correlation between the heat input and the consequential temperature change over time, which can be described by following equation (1).

$$\lambda = \frac{q}{4\pi} \cdot \frac{\Delta T}{\ln(t)} \quad (1)$$

Where ΔT is the temperature change, $\ln(t)$ is the natural logarithm of the measuring time and q is the heat flux per unit length through the wire, which needs to be constant during the entire measurement time. For the present measurements, a transient two hot-wire method is used to determine the heat conductivity of lubricants and lubricant-refrigerant mixtures. The two wires are connected in a Wheatstone bridge and fulfill two functions: They are both heat source as well as temperature sensor. As temperature sensors, they work like a common resistance temperature detectors (RTD) and change their resistance with temperature as seen in equation (2).

$$R(T) = R_0 \cdot (1 + BT) \quad (2)$$

$R(T)$ and R_0 in equation (2) embody the thermal resistance of the wire, where R_0 is the nominal resistance of the wire, B is the metal-specific constant and T the temperature in Kelvin. Thus, the temperature difference can be evaluated by measuring the changing resistance over time.

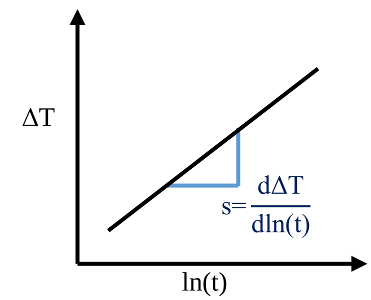


Figure 1: Schematic evaluation of a measurement within the time span in which the thermal conductivity dominates

For the hot-wire method different types of metals are suitable as wire material. The most common and precise metal is platinum (Groot, et al., 1974) (Gross, et al., 1992), but also copper (Azarfar, et al., 2016), tantalum (Garnier, et al., 2008) and nickel (Jwo, et al., 2005) are suitable. For copper and nickel, the temperature range and corrosion resistance are very limited, though (Azarfar, et al., 2016). Figure 1 shows schematically the linear behavior of the temperature difference over the logarithm of the measurement time. By inserting the resulting slope s in equation (1) it can be converted to the following equation (3).

$$\lambda = \frac{q}{4\pi} \cdot \frac{1}{s} \quad (3)$$

Assuming an infinite line source, the heat input per length can be calculated by equation (4), where I is the electric current in A, R is the resistance of the wire in Ω and l is the wire length in m.

$$q = \frac{I^2 R}{l} \quad (4)$$

For a single wire only the middle part of the wire can be considered an infinite line source. For the ends of the wire, boundary effects must be taken into account. By using two wires of different length and different resistance, the boundary effects of both wires can be compensated, as the bridge voltage is sensitive to the relative resistance of the two wires. As a consequence, the two wires can be presumed to be one infinitive line source (Groot, et al., 1974). Equation (4) is then altered to equation (5).

$$q(t) = \left(\frac{U}{2R \cdot \left[1 + \frac{\Delta R(t)}{2R} \right]} \right)^2 \cdot \frac{R \left(1 + \frac{\Delta R(t)}{R} \right)}{l_1 + l_2} \quad (5)$$

$$\approx\left(\frac{U}{2R}\right)^{2}\cdot\frac{R}{l_1+l_2}\cdot\left[1-\left(\frac{\Delta R(t)}{2R}\right)^{2}\right]$$

with R as the initial resistance

$$R=R_1(0)+R_2(0) \tag{6}$$

and ΔR(t) as the resistance at the time t

$$\Delta R(t)=R_1(t)-R_1(0)+R_2(t)-R_2(0) \tag{7}$$

The voltage U is the total voltage across the bridge and l_1 and l_2 are the lengths of the wires (Groot, et al., 1974).

The equations mentioned above are only valid if the heat flux per time is constant during the measurement time. When the heat flow is established during the first 500 milliseconds of the measurement and again when thermal convection sets in, the heat flux varies (Alam, et al., 2017). Hence, the measuring time is sharply limited to the measurement time in between (Groot, et al., 1974).

3 THEORETICAL CALCULATION OF HEAT CONDUCTIVITY OF MIXTURES

If the heat conductivity of the pure components is known, various equations to calculate the heat conductivity of binary liquid mixtures can be found in literature. One of them proposed by Filippov (Poling, et al., 2001) is the Filippov equation, equation (8), where w_1 and w_2 are the mass fractions of the components, λ_1 and λ_2 are the heat conductivity of each component and λ_m is the heat conductivity of the mixture. The constant C can be replaced by an adjustable parameter to fit the data, normally a value of 0.72 is chosen as the starting point.

$$\lambda_m=w_1\cdot\lambda_1+w_2\cdot\lambda_2-C\cdot w_1\cdot w_2\cdot|\lambda_1-\lambda_2| \tag{8}$$

Another calculation method is the Power-Law method. This method applies for binary and ternary mixtures as long as the mixtures are non-aqueous and the heat conductivity does not exceed values of 2 $\frac{W}{m\cdot K}$. In equation (9) the λ_m is the heat conductivity of the mixture, λ_i is the heat conductivity of any pure liquid and w_i is the mass fraction of the component.

$$\lambda_m=\left(\sum_i w_i\lambda_i^{-2}\right)^{-1/2} \tag{9}$$

The expected error for both calculation methods rarely exceeds 5 % (Poling, et al., 2001) for pure liquid mixtures. The applicability for dissolved gas in liquid or refrigerant-oil mixtures has to be checked sufficiently.

4 MEASURING SET-UP

The transient hot-wire method with two platinum wires is used for the described measurements, The two wires as part of the Wheatstone bridge are located inside a pressure resistant measuring cell (up to 40 bars). This cell is then filled with the liquid to be evaluated, i.e. the lubricant or the mixture, and conditioned in a climatic chamber. In Figure 2 the simplified test-rig is shown.

The thickness of the two wires is 20 μm and the lengths are 71.51 mm for the short and 140.35 mm for the long wire. As can be seen in Figure 3, the wires (short wire W_1 and long wire W_2) are connected in series, each with an adjustable resistor (R_2 and R_3) to compensate the Wheatstone bridge. Each adjustable resistor can be varied between 0 and 100 Ω. The rigid arm of the bridge comprises two rigid resistors, R_5 and R_6, of 100 Ω each. Another 100 Ω-resistor R_1 serves as pre-resistor and is used to determine the exact current of the voltage source. To apply a constant and already developed voltage to the Wheatstone bridge, a compensation loop with a resistor R_4 of 100 Ω is installed with the switch S. Prior to the measurement the bridge voltage V is set to zero at a supply voltage of 0.5 V. After switching back to the compensation loop, the supply voltage is increased to 10 V. As soon as the voltage has built up, the measurement can be started by switching to the Wheatstone bridge. The maximum measuring time is 12 seconds, but only data between 0.5 s and 8 s can be used to calculate the heat conductivity. This is the case because the heat flow develops before 0.5 s and convection starts after 8 s. During the measurement, all voltages, i.e. the bridge, are measured over the two wires, over the rigid arm as well as all other resistors.

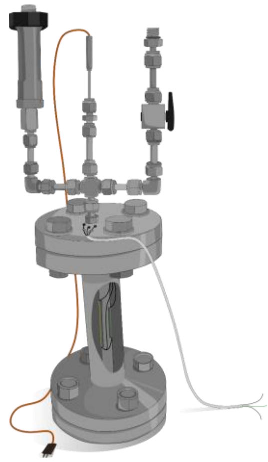


Figure 2: Simplified representation of the test-rig

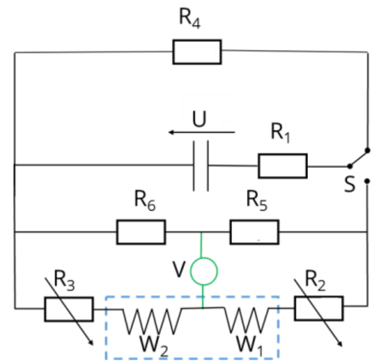


Figure 3: Electric measurement set-up with rigid resistors R_1, R_4, R_5 and R_6 of 100 Ω each, and adjustable resistors R_2 and R_3 each between 0 to 100 Ω, short wire W_1 and long wire W_2

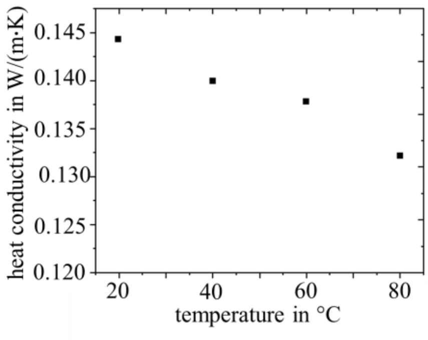
The internal dimensions of the measurement cell are 34.3 mm in diameter and 200 mm in length. Compared to the diameter of the platinum wires, it can be stated that the ratio is approximately 0.001 and therefore no external constraint regarding heat propagation has to be considered for the short measuring period (Tertsinidou, et al.) (Healy, et al.). The two platinum wires are fixed with precious metal supports. They are set in PEAK and connected to the Wheatstone bridge with temperature and chemical resistant single strands. On top of the measuring cell there is a three-cable feed-through for power supply and measurement as well as connections for the temperature and pressure sensor. The measuring system is designed in such a way that the test substances are mixed with low energy and thus each measuring point is recorded in a state of equilibrium.

5 MEASUREMENT

Two refrigeration lubricants, a POE of ISO VG100 and a MO of ISO VG10, their binary mixtures with propane (R290) and methoxymethane (DME) as well as their ternary mixtures with a blend of DME and propane in mass fractions of 5 w% and 10 w% were investigated. Each measurement was recorded at equilibrium and repeated for at least 5 times. All measurements were carried out at temperatures between 20 °C and 80 °C. The internal cell temperature was monitored with a type T thermocouple with an uncertainty of ±0.5 K and the absolute pressure with a pressure transmitter. The uncertainty of the heat conductivity measurement is less than 5 %.

5.1 Pure Lubricant Measurements

In order to determine the change in thermal conductivity caused by the solution of the refrigerant in the lubricant, the heat conductivity of the pure lubricant must first be known. Figure 4 and Figure 5 show the thermal conductivity of the pure lubricants. For both lubricants, the thermal conductivity decreases slightly with increasing temperature. The drop is steeper with POE oil than with MO.



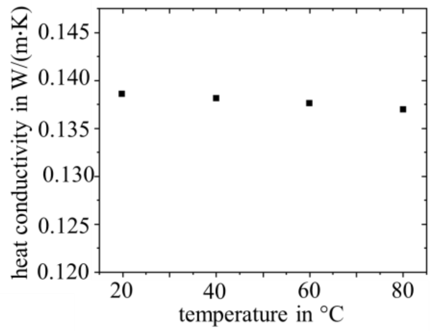


Figure 5: Heat conductivity of MO ISO VG10

5.2 Measurements of binary lubricant refrigerant mixtures

5.2.1 POE VG100 with propane and DME:

The heat conductivity of the pure lubricant is much higher than the heat conductivity of the refrigerants tested. Therefore, the heat conductivity is reduced depending on the amount of refrigerant dissolved in the lubricant. Figure 6 shows the measurements for the pure POE VG100 and its mixtures with 5 w% (45 mol%) and 10 w% (68.58 mol%) of propane. In the temperature range investigated, the thermal conductivity is reduced by 8.15 % for 45 mol% propane and 10.48 % for 68.58 mol% propane compared on average compared to pure lubricant.

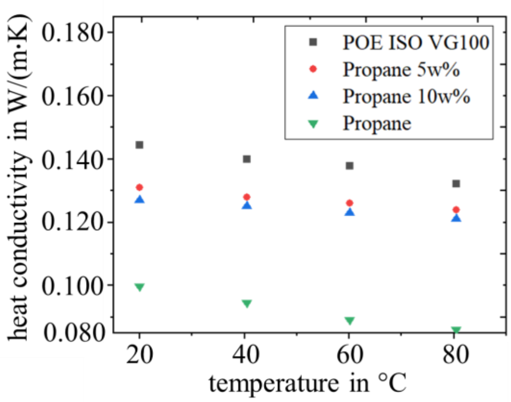


Figure 6: Heat conductivity of POE ISO VG100 with different concentrations of propane

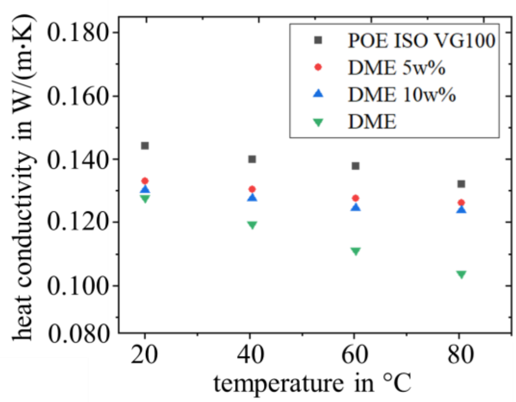


Figure 7: Heat conductivity of POE ISO VG100 with different concentrations of DME

Similar results can be found in measurements with DME. The heat conductivity for 45 mol% and 68.58 mol% compared to those of the pure lubricant is shown in Figure 7. On average, the thermal conductivity for 45 mol% of DME is reduced by 6.62 % and for 10 w% of DME by 9.41 % compared to the pure lubricant. As the concentration of DME increases, the heat conductivity decreases and is between the heat conductivities of the individual components depending on the mass fraction of DME. Comparing the influence of the two refrigerants at same mass fractions and temperatures, the heat conductivity decreases more strongly when propane is used. At mass fractions of 68.58 mol%, the decrease in thermal conductivity is 1.07 % greater and of 45 mol% 1.53 % greater.

5.2.2 MO VG10 with propane and DME:

Figure 8 shows the heat conductivity curve for different mass fractions of propane mixed with the mineral oil. At a mass fraction of 5 w% (27.70 mol%) propane the thermal conductivity decreases by 4.95 % and at 10 w% (42.54 mol%) by an average of 13.85 %. The decrease in heat conductivity as a function of temperature increases with the mass fraction of propane and approaches the decrease of pure propane.

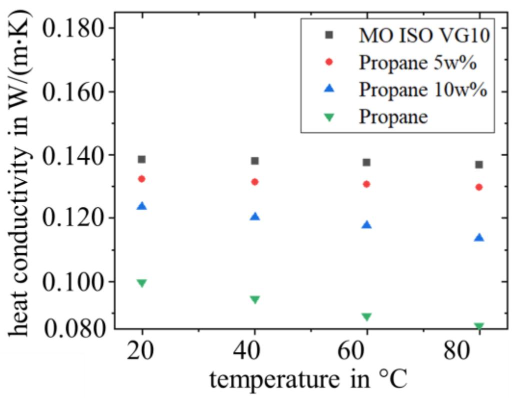


Figure 8: Heat conductivity of MO ISO VG10 with different mass fraction propane

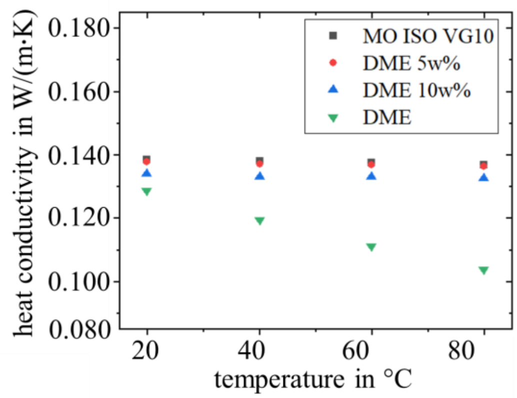


Figure 9: Heat conductivity of MO ISO VG10 with different mass fraction DME

In comparison to propane, the decrease in thermal conductivity is much smaller when using DME, as can be seen in Figure 9. At a mass fractions of 10 w% (44.70 mol%) DME the decrease is about 3.38 % and 0.57 % at a mass fraction of 5 w% (26.83 mol%) DME. However, the decrease within the temperature measurement range is more similar to that of the pure lubricant MO ISO VG10 than that of the binary mixture with propane. In addition to the thermal conductivity measurements of the POE VG100, the binary measurements of the MO ISO VG10 with the refrigerants also arrange themselves between the thermal conductivity curves of the basic materials depending on their composition.

Comparing the two different refrigerants at the same mass fraction and temperature, the heat conductivity decreasing more strongly when propane is used. At a mass fraction of 10 w%, the decrease in thermal conductivity is 10.46 % stronger and at 5 w% 4.38 % greater.

5.3 Ternary measurements

In this paper, ternary mixtures with a blend of DME and propane are investigated for each of the above lubricants.

5.3.1 POE VG100 with propane and DME:

The following investigations are carried out using a blend of 30 w% propane and 70 w% DME. Figure 10 shows the thermal conductivity of the pure lubricant, as well as the two binary mixtures and the ternary mixture at 5 w% (50.21 mol%) mass fraction of the corresponding refrigerant or blend. It can be seen that the propane-lubricant mixture has a slightly lower heat conductivity compared to the DME-lubricant mixture. On average, the refrigerant blend reduces the heat conductivity of the lubricant by about 7.28 %.

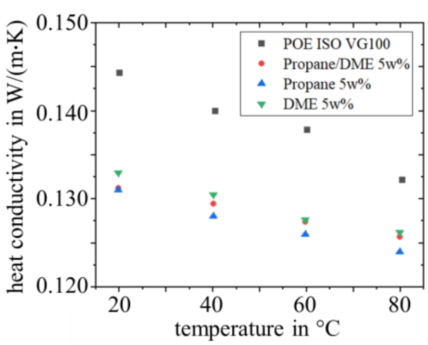


Figure 10: Comparison of the heat conductivity of POE ISO VG100 with 5 w% propane, DME and mixture propane/DME

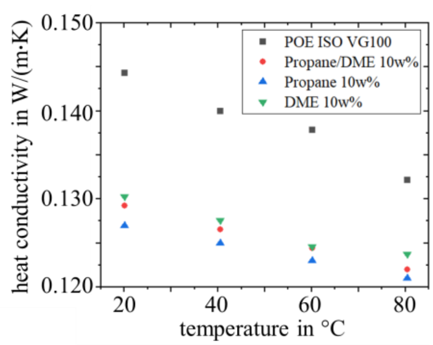


Figure 11: Comparison of the heat conductivity of POE ISO VG100 with 10 w% propane, DME and mixture propane/DME

Figure 11 shows the same comparison for a 10 w% (64.08 mol%) fraction for both binary and ternary mixtures. As the thermal conductivities of the binary mixtures are already very close to each other, no significant deviation can be found. The reduction in thermal conductivity from the ternary mixture to the pure lubricant is on average about 9.38 %.

Figure 12 shows the comparison of the heat conductivity of different mass fractions of the refrigerant blend. According to the mass fraction of the refrigerant, the heat conductivity curves arrange themselves with decreasing heat conductivity with increasing mass fraction. The difference between the heat conductivity of 5 w% (50.21 mol%) and 10 w% (64.08 mol%) refrigerant blend is only 2.1 %. Therefore, it seems that the reduction of the heat conductivity is higher within the first 50.21 mol% refrigerant blend in the mixture.

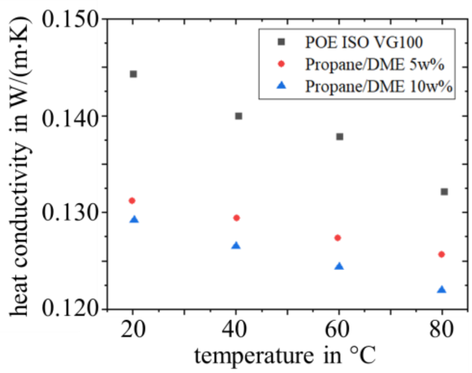


Figure 12: Comparison of the heat conductivity of POE ISO VG100 with 5 w% and 10 w% of the blend

5.3.2 MO VG10 with propane and DME:

The following investigations are carried out using a mixture of 20 w% propane and 80 w% DME. In contrast to the binary mixtures of POE oil, the heat conductivity of binary mixtures with MO oil is significantly different. Figure 13 illustrates the heat conductivity of the pure MO VG10 and that of both binary and ternary mixtures with 5 w% (28.11 mol%). The refrigerant mixture causes a reduction by 4.99 % compared to the pure lubricant. It should also be mentioned that the slope of the ternary mixture is very similar to the binary mixture with propane.

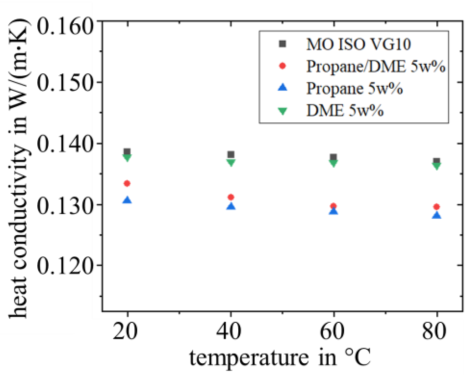


Figure 13: Comparison of the heat conductivity of MO ISO VG10 with 5 w% propane, DME and mixture propane/DME

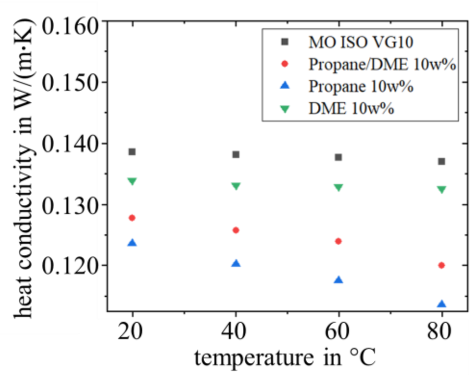


Figure 14: Comparison of the heat conductivity of MO ISO VG10 with 10 w% propane, DME and mixture propane/DME

A similar observation can be made for 10 w% (45.19 mol%) of the refrigerant blend, as shown in Figure 14. The overall average of the 9.78 % reduction in heat conductivity compared to the pure lubricant is between the reductions of the two binary mixtures.

Figure 15 compares the heat conductivity of the ternary mixture in different mass fraction with the pure lubricant. The heat conductivity decreases with increasing mass fraction. According to the mass fraction of the refrigerant, the heat conductivity curves arrange themselves with decreasing heat conductivity with increasing mass fraction.

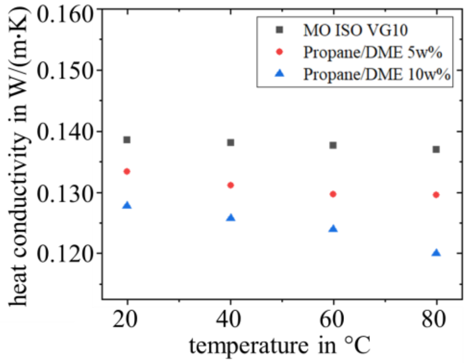


Figure 15: Comparison of the heat conductivity of MO ISO VG10 with 5 w% and 10 w% ternary mixture

6 COMPARISON EXPERIMENTAL AND CALCULATED RESULTS

The binary mixtures are calculated with Filippov, equation (8), and Power-Law, equation (9), whereas for the ternary mixture only the Power-Law is used. All measured and calculated values as well as the deviation of the calculated values from the measured values are listed in Table 1 for the POE and in Table 2 for the MO.

For the Filippov equation the parameter C is adjusted for each binary mixture. The calculated parameter C is 1.43 for the mixture of propane and the lubricant POE ISO VG100 and 3.65 for the mixture of DME and the lubricant POE ISO VG100. For the mixture of DME and MO ISO VG10 the calculated parameter C is 0.12 and for propane 2.68 with MO ISO VG10.

Table 1: Measurement results of binary and ternary mixtures with the POE ISO VG100 and comparison with theoretical calculation

Refrigerant	w%	Temp. (°C)	Pressure (bar)	λ (W/m·K)	$\lambda_{Filippov}$ (W/m·K)	$\lambda_{Power\text{-}Law}$ (W/m·K)	$Error_{Filippov}$ (%)	$Error_{Power\text{-}Law}$ (%)
DME	8.2	20.4	1.96	0.133	0.1397	0.1429	5.06	7.43
DME	7.9	40.4	2.87	0.131	0.1342	0.1383	2.86	6.01
DME	7.6	60.3	4.38	0.128	0.1288	0.1338	0.90	4.74
DME	7.4	80.7	6.59	0.126	0.1234	0.1290	2.32	2.11
DME	10.8	20.0	2.18	0.130	0.1367	0.1420	4.93	9.00
DME	10.0	40.0	3.47	0.128	0.1302	0.1371	2.00	7.43
DME	9.6	60.0	5.26	0.125	0.1237	0.1320	0.73	5.96
DME	9.2	80.2	7.71	0.124	0.1173	0.1268	3.84	2.26
Propane	5.8	20.4	3.38	0.131	0.1376	0.1392	5.06	6.26
Propane	5.6	39.9	4.52	0.128	0.1332	0.1343	4.08	4.94
Propane	5.1	59.7	6.24	0.126	0.1293	0.1297	2.63	2.97
Propane	4.6	79.4	8.01	0.124	0.1255	0.1251	1.19	0.89
Propane	15.9	20.4	6.83	0.127	0.1272	0.1315	0.20	3.58
Propane	13.9	39.9	11.25	0.125	0.1237	0.1268	1.01	1.47
Propane	12.2	59.7	16.40	0.123	0.1204	0.1221	2.11	0.72
Propane	10.8	79.4	19.95	0.121	0.1172	0.1173	3.18	3.05
DME/propane	6.8	19.8	2.91	0.131	-	0.1392	-	6.26
DME/propane	4.9	40.1	3.92	0.129	-	0.1238	-	4.37
DME/propane	4.4	59.7	5.30	0.127	-	0.1213	-	4.77
DME/propane	4.2	79.9	7.12	0.126	-	0.1187	-	5.52
DME/propane	11.5	20.3	6.53	0.129	-	0.1305	-	0.98
DME/propane	11.3	40.0	8.06	0.127	-	0.1267	-	0.15
DME/propane	10.8	60.0	12.03	0.124	-	0.1227	-	1.38
DME/propane	10.0	80.0	16.66	0.122	-	0.1198	-	1.78

Table 2: Measurement results of binary and ternary mixtures with the MO ISO VG10 and comparison with theoretical calculation

Refrigerant	w%	Temp. (°C)	Pressure (bar)	λ (W/m·K)	$\lambda_{\text{Filippov}}$ (W/m·K)	$\lambda_{\text{Power-Law}}$ (W/m·K)	Error $_{\text{Filippov}}$ (%)	Error $_{\text{Power-Law}}$ (%)
DME	4.3	20.1	1.77	0.1378	0.1381	0.1380	0.17	0.16
DME	3.5	40.0	2.15	0.1371	0.1371	0.1369	0.01	0.12
DME	4.0	60.1	3.13	0.1369	0.1361	0.1357	0.58	0.89
DME	6.9	80.0	4.39	0.1365	0.1350	0.1342	1.09	1.68
DME	11.8	19.9	2.72	0.1340	0.1375	0.1375	2.64	2.63
DME	9.5	40.0	3.79	0.1332	0.1361	0.1358	2.15	1.97
DME	12.2	60.0	5.53	0.1330	0.1347	0.1341	1.28	0.81
DME	12.6	79.9	7.94	0.1326	0.1334	0.1323	0.57	0.26
Propane	5.2	20.1	4.85	0.1306	0.1352	0.1348	3.49	3.18
Propane	5.2	39.9	8.21	0.1296	0.1304	0.1328	0.58	2.49
Propane	5.2	59.8	10.42	0.1288	0.1255	0.1305	2.56	1.32
Propane	5.2	80.0	13.85	0.1281	0.1207	0.1278	5.80	0.30
Propane	10.9	20.4	7.67	0.1237	0.1283	0.1319	3.75	6.60
Propane	10.9	39.9	12.02	0.1202	0.1227	0.1289	2.03	7.20
Propane	10.9	59.7	17.56	0.1176	0.1172	0.1255	0.35	6.71
Propane	10.9	79.4	24.05	0.1136	0.1119	0.1216	1.53	6.97
DME/propane	5.5	20.0	1.67	0.1334	-	0.1373	-	2.92
DME/propane	5.5	40.3	2.36	0.1312	-	0.1360	-	3.66
DME/propane	5.5	59.8	3.26	0.1298	-	0.1345	-	3.67
DME/propane	5.5	79.4	4.05	0.1296	-	0.1327	-	2.42
DME/propane	10.9	19.5	6.91	0.1278	-	0.1298	-	1.55
DME/propane	10.9	39.9	11.22	0.1258	-	0.1281	-	1.80
DME/propane	10.9	60.1	17.34	0.1240	-	0.1269	-	2.35
DME/propane	10.9	80.5	20.34	0.1200	-	0.1256	-	4.65

In both cases the deviation of the adjusted Filippov equation Power-Law equation is smaller than that of Power-Law equation. Furthermore, the average error for all MO measurements is smaller than that of the POE. In particular, the Power-Law calculations of the MO show very small deviations, mostly below 5 %, except for measurements with 10 w% propane. But the mean deviation of the adjusted Filippov the binary mixtures with the lubricant MO ISO VG10 equation is with 1.79 % the lowest of all mean deviations. Observing the POE ISO VG100 calculation, the mean deviation of the Power-Law equation for binary mixtures is 4.3 % and ternary about 3.92 %. However, higher deviations of up to 9 % also occur in some cases. In contrast, the adjusted Filippov equation shows a small mean deviation of 2.89 %. All in all, even a small amount of refrigerant or a moderate to slightly increased amount of refrigerant leads to a significant deviation of the theoretically calculated values, which should lead to a detailed consideration of calculation methods.

7 SUMMARY AND OUTLOOK

This investigation illustrates heat conductivity measurements of pure lubricants and their binary and ternary mixtures with the natural refrigerants propane and DME in a temperature range from 20 °C to 80 °C. The mass fraction of the refrigerants and blends was adjusted to 5 w% and 10 w%. The pure lubricants were a polyol ester ISO VG100 and a mineral oil ISO VG10. Depending on the mass fraction of the refrigerant dissolved in the lubricant, the thermal conductivity of the lubricant is reduced. When comparing the calculated values using the Filippov and Power-Law equations for liquid mixtures with the measured values, a deviation of usually less than 9 % for the Power-Law equation and less than 5 % for the adjusted Filippov equation is found for both lubricants. Epically the deviation of the Power-Law equation is higher than the theoretical error should be and the experimental measurement of the heat conductivity is to be preferred. determine values of the binary mixtures within the measured temperature range and the refrigerant mass fraction used, interpolation can be carried out using the adapted Filippov equation.

In the future, the influence of the different lubricant types and refrigerant combinations on the calculation will be considered. Furthermore an investigation for high refrigerant amounts and there influence of the deviation between common calculation and measurement data should be done. In this context, a modification of the equations to consider solubility, miscibility and the resulting shift in composition could be considered.

NOMENCLATURE

I	current	A
l	length	m
R	resistance	Ω
T	temperature	°C
ΔT	temperature difference	K
t	time	s
U	Voltage	V
q	heat flux	W/m
λ	heat conductivity	W/m·K

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ACKNOWLEDGEMENT

The here presented investigations were performed within the scope of the project REFMIX sponsored by the German Federal Ministry of Education and Research, BMBF. REFMIX is a bilateral project executed by the TU Dresden on the German side and the Istanbul TU on the Turkish side. Moreover, we want to thank FUCHS Schmierstoffe GmbH for choosing and supplying lubricants.